A general framework to estimate loss sources and magnitudes in live-ruminant post-production in developing countries

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Introduction

The purpose of this paper is to review existing knowledge on analytical approaches to food losses in the primary sector and to adapt that specifically to livestock value chain..

The interest in losses in food systems is not new. This issue is in the agenda of the United Nations that declare drastic reduction of postproduction losses after the mid-1970s food crisis a priority (FAO, 1981). After a period of disinterest, losses in food systems are once again a major concern. Since the 2007-2008 world food crisis, increasing attention is given to supply and demand components of agricultural and livestock products (World Bank, 2011; Kaminski and Christiaensen, 2014) to better capture losses and wastes along commodity and animal value-chains (Lipinski et al., 2013). This is the backdrop to the implementation of the African Postharvest Losses Information System (APHLIS) by the European Commission in 2009 in order to provide estimates of postharvest cereal weight losses in Sub-Saharan Africa.

Food losses have an impact on food security and food safety for poor people (Sheahan and Barrett, 2016) as well as on economic development and the environment (Gustavsson, 2011). More generally, four important objectives underlying actions against food losses: improving food security (Barrett, 2015; Christiaensen and Demery, 2007); improving food safety (Swinnen et al, 2015); reducing waste and optimizing use (Sheahan and Barrett, 2014); and increasing profitability along the value-chains (Gómez and Ricketts, 2013; Affognon et al, 2015). Food loss is economically significant in developing countries for a broad range of commodities, resulting potentially in a substantial negative impact on food security and livelihoods. It is arguable that efforts in reducing food losses, including postharvest losses, will have a positive effect on food security (Gustavsson, 2011). With this objective, the United Nations are intending to promote worldwide food waste and drastic food loss by 2030 as component of its Sustainable Development Goals agenda. This approach has the potential to significantly galvanize renewed and globalized attention on reduction of food loss and waste along primary sector value chains.

Beyond productivity issues that lead to sub-optimal performance, food loss and waste departs from the production stage and usually is addressed through various interchangeable notions such as “postproduction”, “postharvest loss,” “food loss,” “food waste,” and “food loss and waste” without consistently reflecting the same aspects of the problem (Schuster and Torero, 2016).

Food loss refers to the decrease in edible food quantity or nutritional value or quality, which makes it unfit for human consumption (FAO, 2011, 2013; Aramyan and Gogh, 2014). Fundamentally, this definition seems to neglect loss in economic value. A meta-analysis conducted by Affognon et al. (2015) in Sub-Saharan Africa showed some methodological limitations with over 80 percent of all studies focused on on-farm storage level. On the other hand, Mrema, (2012) argued that interventions to reduce food loss need to cover the entire system and not portions of it since post-harvest systems in the 21st Century are more complex compared to those in the 20th Century. Hence, reducing food loss first requires an understanding of complexity encountered at various levels and stages of the supply chain, and then implementing the suitable solutions.

Despite the incontestable advantages to reduce food loss in a multi-scale approach, there is currently no recognized coordinating mechanism at the international level for tackling PHLs (FAO-World Bank, 2010). The degree of food loss in developing countries is relatively unknown and when quantified, it is merely guess-estimates (as best-guess-estimates) derived from questionnaires rather than actual measurements. In addition, little work has been done on developing methods to assess post-harvest losses especially in livestock. FAO-World Bank (2010) proposes a value chain approach and the use of social marketing approaches for assessing PHLs.

Additionally, there is a dearth of consistent methods and applications to measure losses in livestock commodity value chains, especially in pastoral systems. One reason pertains to the difficulty to define and quantify losses related to live animals. For instance, accidents during transport to the market, loss of body weight as a result of stress and disease during transport, or seasonal adjustments during marketing period are important factors that affect the price a seller receives at the point of sale. More research and evidence regarding the extent of losses at various levels of live animal value chain (i.e., production, transport, and marketing) are needed. Such evidence is necessary to identify the points of inefficiencies and the needed interventions to reduce losses. To achieve this, there is need to design a common methodology, appropriate sampling framework and to design appropriate tools to collect data. This is needed for accurate assessment of post-production losses that leads to informed policies to improve value chain performance. This ambitious orientation would spur development and guide research and interventions on post-production losses in Sub-Saharan Africa for various reasons: (1) improving food security, (2) improving food safety, (3) optimizing resource use and (4) enhancing profits for value chain actors (Sheahan and Barrett, 2016).

Intrinsically, there is no consensus on the methodology of post-production assessment although from Bourne (1977) to Sheahan and Barrett (2016) the sources of losses have been described from the farm-to-fork. In a nutshell, despite a diverse range of methodological approaches on PHL assessment in grain and crop areas, there is no conclusive evidence on the magnitude of quantity and quality losses in food value chains. The problem is more acute for livestock sector in developing countries.

Usually when food loss issues are evoked, quantitative and qualitative magnitude estimates are commonly followed and then by remediating them ("zero" loss approach). However, an alternative economic perspective would be to: Show that all losses are not undesirable, provide a loss assessment method in value and to alleviate them as economically possible as ("optimal" loss approach). The main assumption is to consider that total elimination of losses could be a costly and prohibitive process given that whatever the availability and access to technology, innovation and institutional arrangement, a certain level of loss is inevitable and desirable in some cases particularly in agricultural sector. So, this document opts to; (1) address issues in pastoral live-ruminant animals that are poorly documented; (***2)*** proceed to an in-depth critical literature review; (***3)*** challenge many concepts and notions used interchangeably to choose those fitting more to the intrinsic characteristics of people living under stress conditions in Drylands areas; (***4)*** propose best-bets on the relevance of the "optimal" loss approach and finally, (***5)*** provide a general framework based on pastoral and agro-pastoral household behaviors and motivations to sell live-ruminants when they are exposed to exogenous shocks even if constraints influence the performances of livestock production systems.

1- THE LOSS MAGNITUDE CHALLENGE

Food loss and waste is a subject that is well known or at least receives high profile in the media, but little acknowledged as a difficult concept to measure. Addressing food loss and waste issues is faced with a conceptual challenge of knowing/ establishing what is lost, compared to some counter-factual, and the of that loss. The challenge is also in terms of food security, food safety, economic and environmental aspects: food loss and waste means part of the land, water, labor, seed, pesticide and fertilizer – so a financial and environmental loss too. The desire and dedication to measure post-production losses are not new. In the past, this was conducted on the development of innovative assessment techniques and approaches (Harris and Lindblad, 1978; National Academy of Sciences, 1978). What is really new is the upsurge of interest and the efforts to tackle this issue in Sub-Saharan Africa through the implementation of the African Postharvest Losses Information System (APHLIS) mobilizing various local experts, a loss calculator and free access database (Hodges et al, 2010; 2011).

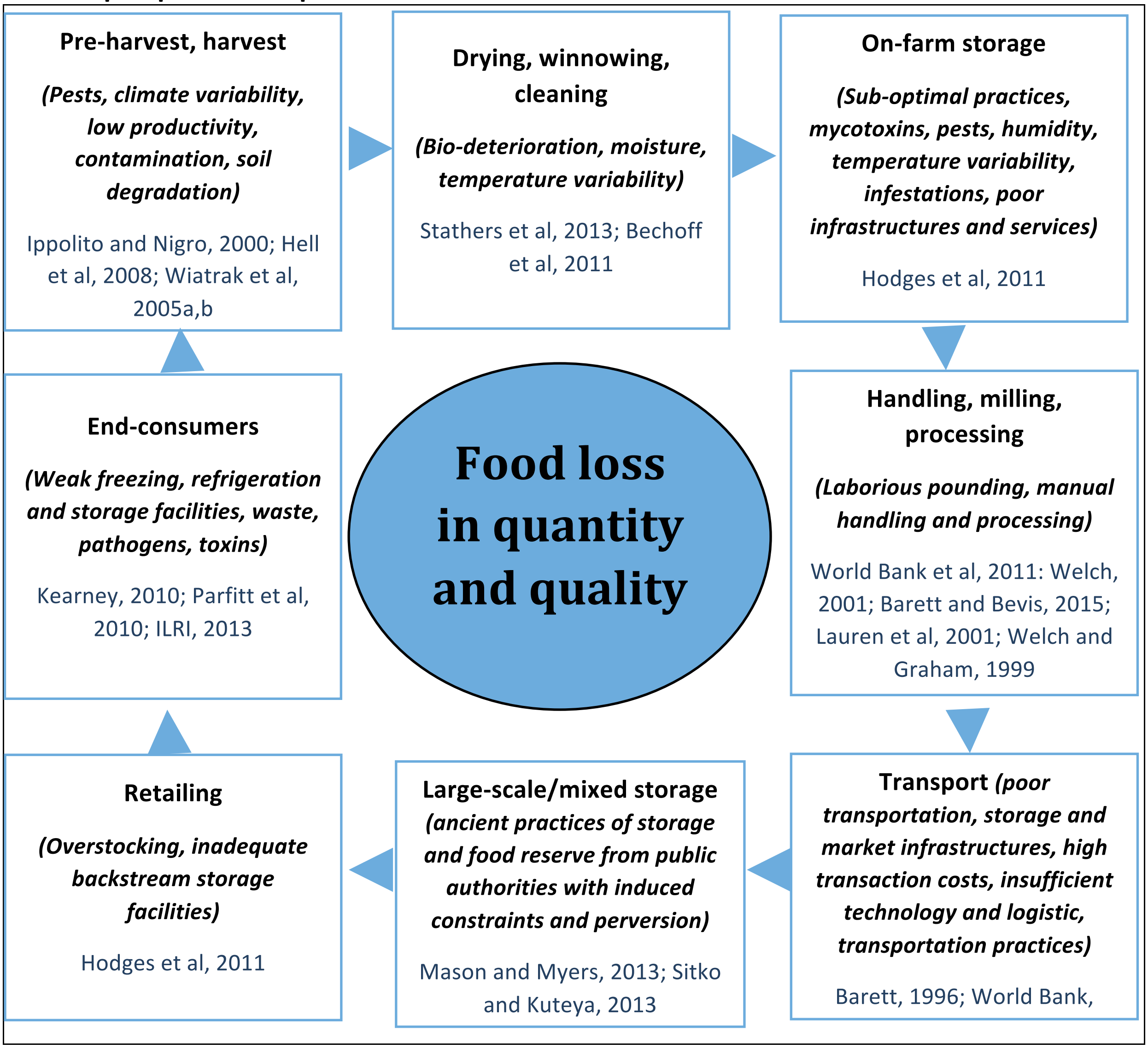
1.1. Lessons learnt from the crop systems

There is a wide spectrum of food loss definitions, more or less nuanced, going from an operational conceptual approach (FAO, 2011, 2013; Aramyan and Gogh, 2014; de Gorter, 2014; Parfitt et al, 2010; Hodges, et al., 2011; Bourne, 1977) to a more complex one (Papargyropoulou et al., 2014).

Food loss occurs at production, pre-harvest, harvest and post-harvest stages (Parfitt et al, 2010) while food waste is related to the portion not consumed and discarded as waste at some point in the product chain (Hodges, Buzby and Bennett, 2011). Food loss and waste is a subject that is well known in particular in terms of where and how losses occurred (Figure 1).

However, it is little acknowledged that food losses and waste are difficult to measure. Several contributions have been done on the estimates of loss magnitudes particularly in grain and crop sectors. The first ones using mass flow models set both loss and waste in food systems at one third of the physical mass of all food around the world (FAO, 2011) converted by Lipinski et al. (2013) to 23% into calorie terms. More specifically in Sub-Saharan Africa, the World Bank (2011) reported yearly grain losses in financial terms for around USD 4 billion. Although it is very useful to highlight these issues for donors and funding agencies, these global figures are increasingly challenged especially in Sub-Saharan Africa where recent scientific works has shown that there is an overestimation of loss magnitudes since the reality is; the estimates range between 4% in presence of prevention mechanisms to 20% otherwise (in absence of preventive mechanism) (Affognon et al., 2015; Rosegrant et al., 2015). In the dairy sector, FAO (2012) estimated that milk losses in sub-Saharan Africa amounted to 27% and in low-income countries, these losses occur mainly in early or mid-food chain, and are partly based on assumptions of reduced value when auto-consumed. However, an extensive fieldwork conducted by CIRAD and its partners on evaluation of losses throughout the dairy supply chain (from producer to distributor) in Senegal and Burkina Faso in 2016 valued the total losses between 4 and 14% of milk produced which is far from FAO estimates.

Figure 1. Sources of quantity and quality food losses as well as loss in economic value in crucial postproduction phases



Source: Sheahan and Barrett, 2016

The key challenge is on methodological approaches, which have so far been designed and applied in developing countries relying on experiences from developed countries (Sheahan and Barrett, 2016). However, efforts have been made by European Union to support Sub-Saharan African countries in 2009 to implement the African Postharvest Losses Information

System (APHLIS) in order to integrate a network of local experts for supplying data and sharing a database on weight losses of cereal grains by country and by province (Hodges et al., 2010; Rembold et al., 2011) on a basis of an oversimplified PHL environment and a low challenge of input data quality (Affognon et al., 2015).

At micro level, cross-country surveys at farmer scale on post-harvest losses across Sub-Saharan Africa reveal interesting findings with relative low indicators ranging from 1.4 to 6.9 % of total production (Kaminski and Christiaensen, 2014; Abdoulaye et al, 2015). Although designed on large samples, these surveys cannot easily be generalized at national level as these cases have not initially designed for this perspective.

In a value chain perspective, beyond variation in magnitude, it seems that loss of grains and cereals occurs more during handling and storage on-farm phases while loss of fresh products is more reported during processing and distribution phases. In technical perspective, this consensus on loss distribution from the farm-to-fork could be explained by the fact that most of identified surveys insisted more on losses in on-farm storage (Affognon et al, 2015). However current trends and projections on food value chains challenged these methodological approaches that should integrate chain modifications due to various drivers such as urbanization.

It still remains a powerful analytical tool for describing complex interactions between physical and social systems, and for guiding actions to enhance well-being through reduction of loss in the primary sector. New insights on estimation of food loss and waste particularly in livestock sector could contribute to a re-emerging and converging research agenda on the challenges faced by people living under growing stresses caused by global environmental and social change.

1.2. “Zero” loss *versus* “Optimal” loss

Would it be economically possible to imagine reaching “zero” loss situation? Through this question, we try to structure the debate between the proponents of loss eradication along agricultural value chains given the food security challenges and those, more pragmatic, in favor of alleviating loss through optimization approaches.

Whatever the adoption level of technologies, innovations and institutional arrangements, it is reasonable to assume that eliminating all sorts of loss in agricultural value chains is a costly and prohibitive process. Accepting a certain level of failure and losses that inevitably comes with a risky context could be economically rational as it is impossible to avoid any contamination or spoilage (de Gorter, 2014). This in effect establishes a counter-factual against which losses and waste can be empirically measured.

By assuming that a certain level of losses in agricultural value chains might prove necessary and even economically rational, the effort should be to better address microeconomic behaviors underpinning potential sources of losses before developing strategies to alleviate effects of individual decisions (Sheahan and Barrett, 2016; Barrett, 2015; de Gorter, 2014; Goldsmith, et al., 2015; Waterfield and Zilberman, 2012). Quantity losses might also arise from voluntary and intentional decisions of economic actors in particular those focusing on profit and not production maximization as was the case of Brazilian soybean farmers

(Goldsmith, et al., 2015). It is also possible in terms of food safety that losses might be desirable when after production, unsafe food is removed from the system to avoid human or animal contamination (Magoha et al., 2014).

In a dynamic household analysis, the management of losses at farm level could provide mixed results. For instance, by expecting losses due to lack of storage facilities, farmers could be forced to sell their available products in a context of low market prices. In this case, quantitative losses could be low while value related losses very high as was the case with farmers from Benin (Kodjo et al, 2015).

Since “Zero” loss could be seen as an unattainable ideal in particular in the current Sub-Saharan livestock contexts, we can tangentially use a counter-factual based “Optimal” loss approach that is more relevant to economically motivated producers and market actors.

2. THE MEASUREMENT CHALLENGE IN THE SAHELIAN LIVE-RUMINANT POST-PRODUCTION

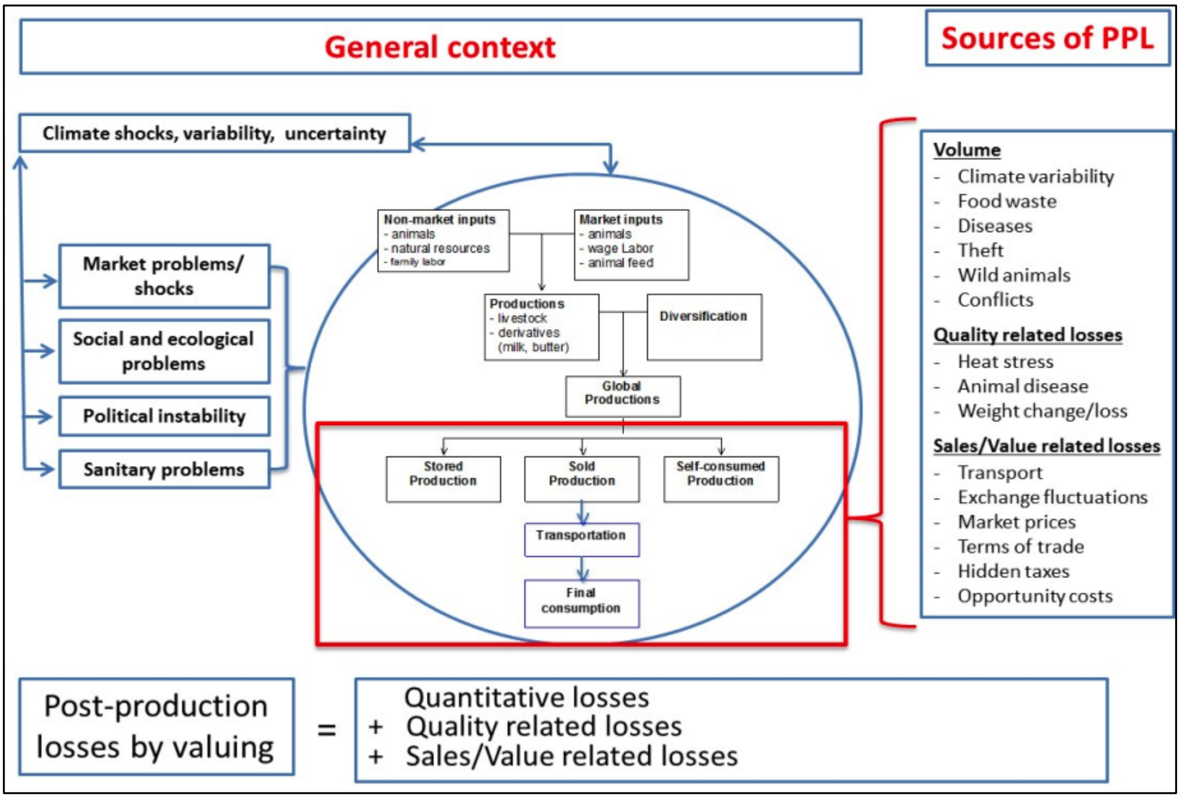
Food loss and waste has been and still is a powerful analytical tool today for describing complex interactions between physical and social systems, and for guiding actions to enhance well-being through reduction of loss in the primary sector. New insights into food loss and waste estimation particularly in livestock sector could contribute to a re-emerging and converging research agenda on the challenges faced by people living under growing stresses emanating from global environmental and social change.

2.1. Tackling post-production losses in complex animal production systems

In West Africa, animal production systems and social livelihoods usually evolve in a context of risks, uncertainties and opportunities that lead to permanent change impacting socio-ecosystems simultaneously, sequentially, or sometimes in isolation (Wane *et al.*, 2010). Climate change may play a central role by having a direct impact on natural resource dynamics pushing herders to deal with spatiotemporal variations by using mobility as main strategy of risk management. It is a factor that indeed aggravates the economic, social, cultural and political problems (price volatility of food and feed at the national and international levels, diseases, political instability, social transformations, etc.) of societies.

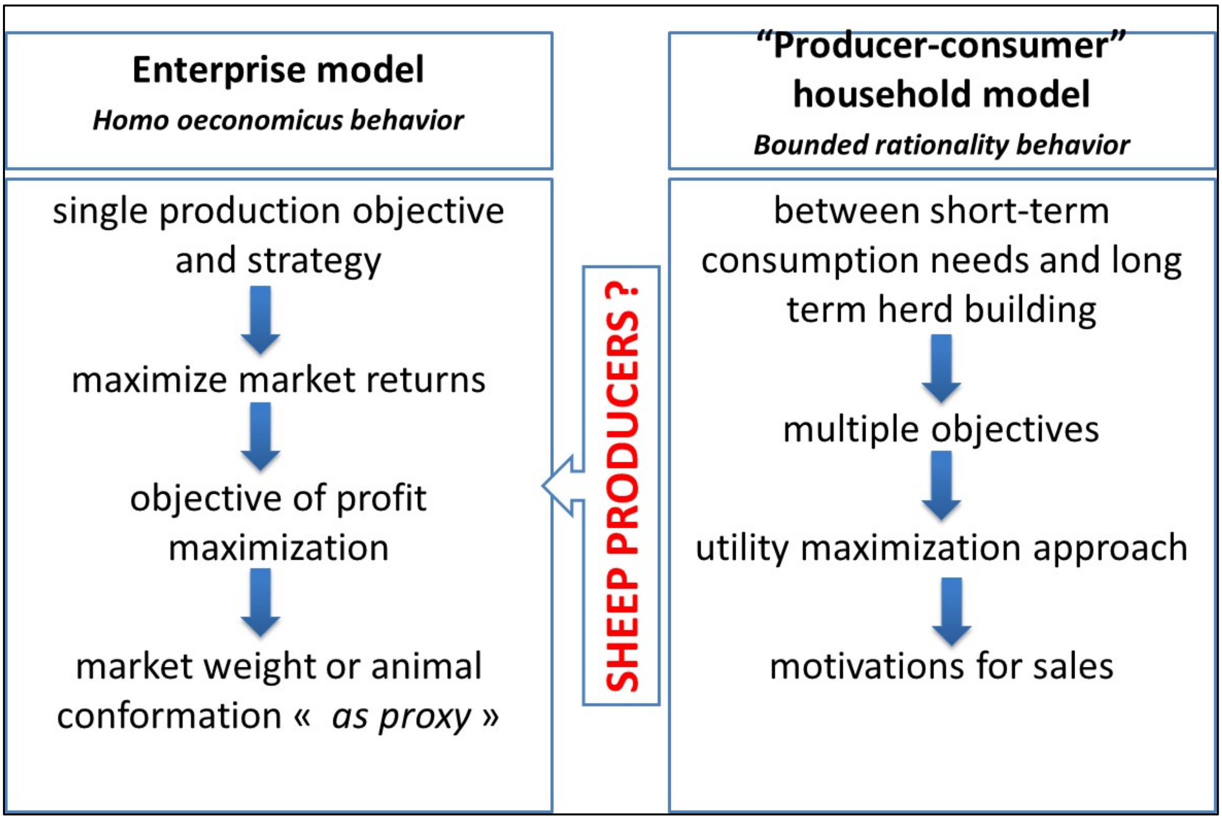
The livestock production in the Sahel is carried out in an environment of severe socio-ecosystem constraints, as well as a deficit in infrastructure, social and economic basic services, and a sub-optimal and unfavorable environment (very low portion of investments in the agricultural sector and difficulties in applying laws and regulations adapted to livestock dynamics). In addition to these constraints, the livestock sub-sector has the characteristic of being sensitive to the occurrence of various types of disturbances. The main disruption is the climate risk, which acts both as a major risk factor exacerbating other economic, health, and socio-demographic and political shocks. Modes of livestock production can broadly be described as; a combination of non-market inputs and market inputs to produce ruminants and livestock products (meat, fresh milk, curd, butter, hides and skins). The portion sold follows a specific value chain involving many stakeholders until the end-consumers. Figure 2 provides a framework to identify main sources of post-production losses in the Sahelian live-ruminant post-production.

Figure 2. Conceptual framework of PPL in the Sahelian live animals' value chain



Empirically, what could characterize and differentiate the intensive, semi-intensive and extensive systems, beyond production aspects, are the market differing behaviors of producers. On the one side, live animal producers in intensive and to less extent in semi-intensive systems are profit-optimizers who participate in markets largely to buy livestock as inputs, fatten them after some time, and sell them as finished products at premium prices. On the other side, producers in extensive systems try to secure both production and livelihoods objectives considering the overall uncertain context (Benkhe and Scoones, 1983; Wane *et al.*, 2010). The objective function of producers in extensive and pastoralist systems is a composite utility function that balances their short-term consumption needs and long term herd building strategy to meet future consumption. For these reasons, they participate in a market(s) in an opportunistic way. Their motivations for sales become a key element to fully understand. (**Figure 3**).

Figure 3. Duality of animal production models in the Sahel



These two models coexist across countries, production areas and even in households according to the period of sales and species. For instance, in Senegal, the main goals of pastoral households for selling livestock and animal products are to make money to cover their usual expenses and ensure food safety. During the Aid-al-Udha, the demand for livestock and animal product is very high, so they develop a pure *homo oeconomicus* behavior to sell as many sheep as possible.

Addressing postproduction losses in this context requires developing of a dual approach as suggested for public policies for livestock development (Ly et al., 2010; Nouala et al., 2011).

Market fundamentals are not the primary drivers, but cultural, social, and non-commercial factors also play a significant role in producers' decisions to sell. A consistent literature on inequality (Sen, 1981; Sutter, 1987; Wane *et al.*, 2009; Mulder *et al.*, 2010) and vulnerability of pastoral populations (Swift, 1989; Ancey *et al.*, 2009) show the complexity of pastoral risk management, as it is necessary to take into account the embedding between social and biophysical factors particularly in African extensive crop–livestock systems. So, extensive systems cannot be measured in pure terms of endowments as they continually evolve and adapt to accommodate (entitlements) an increasingly uncertain biophysical environment and monetized commercial world (Chambers, 1990; Van Dijk, 1997; Bovin, 2000).

2.1.1. Relevancy and challenge to work in the Sahelian live-ruminant post-production

In the Sahel, livestock is more of the extensive type and mainly organized around the production of live-ruminants to supply local and regional consumers. In economic terms, this activity provides a variety of benefits; the most important is the monetary income that farmers can derive from them.

For instance in Senegal, 97.9% of the livestock farming income comes from the marketing/ trade of ruminants (bovines contributing 40% and small ruminants 60%) (Wane et al., 2010). Sale of dairy by-products (fresh and curdled milk, butter) remains marginal (0.50%) and is conversely linked to the degree of enclosure of the herders' places of residence and activity. The diversification of production and the activities is not apparent in the activities of selling. (Wane et al., 2015).

The situation of livestock in Senegal is mixed and is threatened by a number of risks which could lead to physical and financial damage and losses (d'Alessandro et al., 2015). Although difficult to measure due to real data gaps, we were able to simulate the financial impacts of the identified risks. Under certain assumptions, that should be however interpreted with a great deal of caution, the minimum inaction costs of risks are annually estimated at XOF 601.05 billion, around USD 1 billion at the current value. (Wane and Mballo, 2016).

Despite its importance and key function in the Economics of Drylands (Ickowicz et al., 2012; de Haan et al., 2016), live-ruminants did not receive much attention from past research on post-production losses that has mostly focused on crops and in lesser extent, dairy and meat sector. Even if we can note interesting contributions aiming broadly the value of livestock loss related to unexpected shocks and more particularly how their outputs and inputs would be affected by exogenous shocks (Halloway, 2012). More specifically the value of livestock losses on livelihoods were addressed among Ethiopian Highland pastoralists through dairy production (Adesugba, 2014). By contrast to the live-ruminant post-production, other livestock commodity value chains benefitted from more attention. It is the case of the Sub-Saharan dairy sector with an extensive fieldwork conducted by CIRAD and its partners in 2016[1] on the magnitude of losses throughout the dairy supply chain in Senegal and Burkina Faso, valued the total losses between 4 and 14% of the milk produced. This is lower than FAO estimates that milk losses in sub-Saharan Africa amounted to 27% and occurs mainly in early or mid-food chain (FAO, 2012).

In this situation, mitigating the challenge to address loss issues in live-ruminant post-production becomes relevantly an important stake for Sub-Saharan countries and for exploratory purposes. In the Sahel, measuring losses at farm level is a critical issue to tackle while implementing traditional approaches to the rest of the value chain seems to be an easy way.

[1] This is an ongoing research called REGAL (2015-2017) and led by CIRAD in the multi-year metaprogramme "GloFoodS" (Transitions to global food security) dedicated to the investigation of pathways to worldwide food security in a context of competition for land and natural resources. The objective of the REGAL project is to design and evaluate supply-demand adjustment scenarios to reduce losses and wastage along dairy supply chains in West Africa (Senegal and Burkina Faso).

2.2. The starting-point dilemma

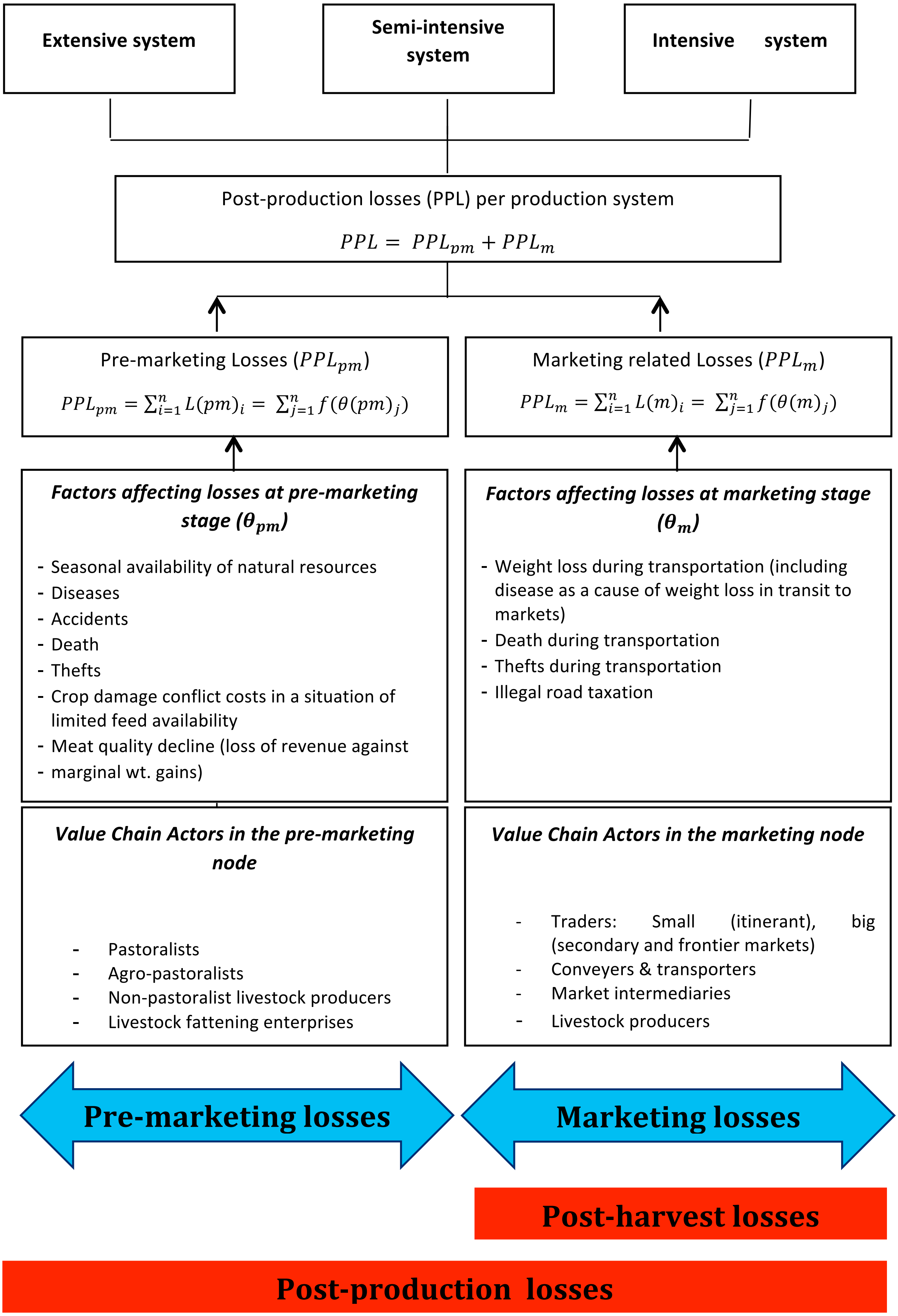
Focusing on PHL to provide a consistent and comprehensive framework for identifying the main sources of losses and their estimates does not reduce the complexity of the task, as there is an additional layer of difficulty pertaining to the choice of counterfactuals to which these losses are measured.

Naturally, one would expect these counterfactuals to be different, depending on the production systems. For extensive production system, producers generally retain the females and sell the steers. The useful life of a Zebu cow under this system varies between 4.5 and 8.5 years during which it has on average 5.1 parturitions, including abortions (Mukassa-Mugerwa, 1989). Hence culling a cow once it completes its useful years could be considered as an efficient husbandry principle and could be used as counterfactuals. For semi-intensive and intensive systems, cows, steers, and oxen are important and are held for different purposes. Fattened steers and oxen can be optimally marketed when they reach 250 kilograms of live weight as can an eight and a half year old cow. These can be regarded as thresholds to establish a counterfactuals against which losses can be measured.. A similar reasoning could be provided for sheep and goat.

Once produced in each production systems (extensive, semi-intensive, intensive), live-animals are moved along the value chain to downstream markets for their final use. At each stage along these different chains, losses occur due to various factors. **(Figure 4**). For livestock systems and particularly, in Sub-Saharan Africa, this is the central theme of the debate that could not occur in crop systems. Notions of "postproduction loss" and "postharvest loss" are used interchangeably to reflect specific problems in the agricultural sector. These concepts mobilize aspects related to temporal dimension whether the purpose of the study concerns an element with products ended life cycle (meat, milk, cereals) or live-animals (ruminants), to nature of the product: perishable (meat, milk) or non-perishable (cereals) food stuffs etc. This interchangeability might be a new phenomenon while Bourne (1977) already made an operational distinction based on three periods of time during which food loss occurred: "***pre-harvest***", "***harvest***" and "***post-harvest***" periods. Thus, this segmentation allowed combining of losses during "harvest" and "post-harvest" periods into a single category called post-production losses.

From our perspective, the fact that we are working in life sciences means reaching the boundaries as previously defined by Bourne (1977) by considering the equivalent of the "pre-harvest" periods to better address livestock dynamics in developing countries. Thus, it seems more relevant to work on "***post-production losses***" by integrating losses during the pre-marketing" phase and those during the "marketing" phase. **(Figure 4**).

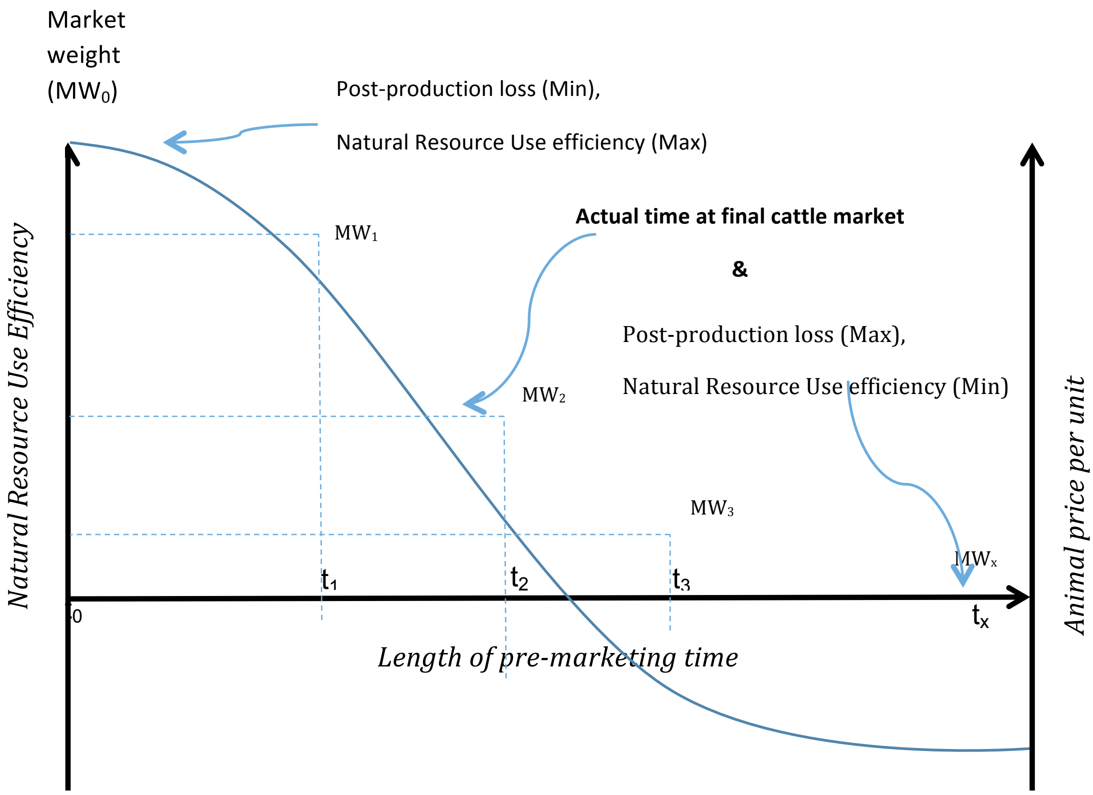
Figure 4. Factors affecting post-production losses at each critical stage



2.2. Constraint management (productivity gap) *versus* Risk management (losses)

Risks are changing events that lead to losses while constraints could be seen as permanent conditions that lead to sub-optimal performance. Almost all Sahelian countries experience lack or bad infrastructure functioning (lack of rural roads, market or storage facilities) and asymmetrical distribution and variable natural resources. This finally becomes a structural constraint and makes smallholders unable to generate the production and revenues they expected. On the other hand, risks provoke losses by livestock keepers on an infrequent basis. Most of the time, notions of risks and constraints are interchangeable and even strongly linked so that it is sometimes difficult to distinguish them in particular in the Sahelian production systems. For instance, to estimate post-production losses particularly in the complex extensive system, we may have to consider (***1)*** the following animal classification "Steers – Bulls - Culled oxen – Culled cows" based on existing knowledge of these systems; and (***2)*** an approximate average age for each class.

Figure 5. Depicting the relationships between delayed marketing, natural resource use efficiency, animal standards and related revenue loss even with marginal weight gains



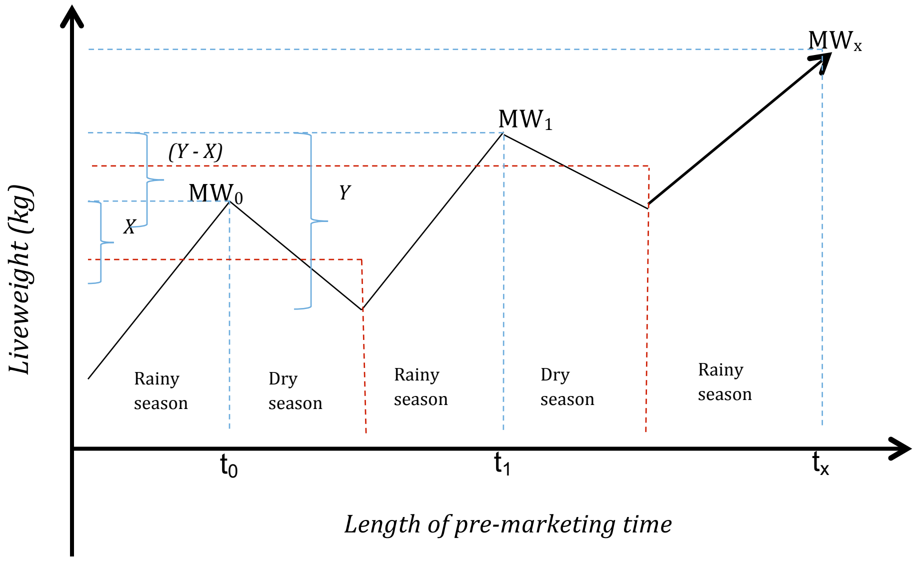
Therefore, post-production loss for an animal is the sum of losses incurred from the time when an animal reaches market weight or ideal market age (mainly for pastoralists who are not driven by market weight)[2] to the time it reaches the final market. The period in-between

[2] It is also possible to have a positive impact (gain) to natural resource use efficiency. To minimize potential losses and risk, some producers sell the animal before it reaches market weight. Sometimes they sell weaners in response to weaner higher prices. For example, in the weaner-oxen marketing systems, the weaner will still

is referred to as the pre-marketing time, which could be considered as the equivalent of storage period in crops agriculture. The duration of pre-marketing period has several implications including losses related to the animal itself as well as natural resource use efficiency. For example, after attaining market weight, animals that are kept longer go through seasonal fluctuations in feed availability characterized by balancing weight loss and weight regain (**Figure 5**).

Whether in extensive systems or supplemented semi-intensive and intensive systems, the feed resources used to return an animal to a previously attained weight is viewed here as a loss or decrease in natural resource use efficiency. These types of pre-marketing losses are less discussed though they could have a substantial magnitude on overall losses than the more recognized losses that occur between farm-gate and final market.

Figure 6. Seasonal weight losses and gains during the dry and rainy seasons



In **Figure 6**, MW_0 represents market weight for a given species e.g. 250 kilograms live weight (*kg/LW*) for cattle, 25 *kg/LW* for goats while t_0 is the time when MW_0 has been attained. Following this, t_1 is the corresponding period in the following year, which then encompasses a season of feed scarcity (usually dry season when the animal loses *X* kg) and a season of feed availability (usually rainy season when the animal gains *Y* kg).

In the above scenarios $MW_1 = MW_0 + (Y - X)$, where $(Y - X)$ is the marginal weight gain attained using resources that are otherwise adequate to gain *Y* kg (Figure 6). The higher *X* is, the more substantial is the loss of feed resource that could have been put to alternative use and this can be calculated (call it *FR*). This means that an animal that is kept for a single time period (*T*) causes a loss of a unit of *FR* while an animal that is kept for T_x time periods must have caused the loss of *FR* times T_x.

get fattened and get re-sold, but the producer/owner sells it before it actually reaches market weight. This case seems not to respond to our research issue that focuses on losses.

Other pre-marketing losses include labor and husbandry costs invested to regain lost weight per period, loss in price per *kg/LW* due to decline in meat quality over time, etc. The other variables related to pre-marketing and marketing losses could be captured and measured from field investigations (value chain actors' questionnaires and focus group discussions). To note that these discussions are based on the profit model and neglect the multiple objectives of cattle keeping, including assets for financing and insurance, building of social capital, retention of breeding animals, etc. These are gains associated with keeping animals beyond market age/weight and should be included.

All this approach usefully illustrates the strong complexity of animal production systems in Sub-Saharan Africa with some actors' behaviors driven by market weight (intensive and in extent semi-intensive systems) while other ones reasoning in terms of ideal market age (extensive systems). The second major lesson comes from the statement of the missing knowledge in extensive systems where post-production losses seem to be underestimated in particular more at the pastoral household level than the rest of the value chain nodes.

Alternatively, we propose to simplify the previous model that fits more to also take into account productivity gap issues and to make a clear distinction between constraints and risks. We will insist more on risk issues in the following development of our conceptual framework.

3. A GENERAL FRAMEWORK TO ESTIMATE LOSS MAGNITUDE IN THE SAHELIAN LIVE-RUMINANT POST-PRODUCTION

Analysis of post-production losses in live-ruminant value chains is still in an embryonic phase. In modeling these losses our study will distinguish two stages: (1) On the one hand, we will focused on the producers' node which require a more in-depth conceptual and empirical investigation and being the most ignored, (2) On the other hand, examine the main stakeholders in the live-ruminant value chain where the conventional methods of measurement are potentially applicable.

3.2. Post-production losses in live-ruminant at producer level

Livestock are the sole source of livelihood for an estimated 25–41 million people and provide a significant share of income for an additional 72–94 million people in the Sahel and the Horn of Africa (de Haan, 2016). In the Sahel, livestock trade is almost dominated by live-ruminants with the total value increasing from US$13 million in 1970 to US$150 million in 2000 in real terms (Williams, Spycher, and Okike 2004). Livestock trade has helped the Sahelian countries keep the pace of rising internal demand (Delgado et al, 1999) and that of coastal countries. Trade follows three main corridors and involves important exporters (Mauritania, Mali, Burkina Faso, Niger, Cameroon and Chad) to big importers (Senegal, Cote d'Ivoire and Nigeria). In some cases live animals pass through Benin and Togo for the Eastern corridor. High transaction costs are incurred during internal and cross-border live-animals'. For instance, transportation and handling costs can be as high as 40–60 percent of costs incurred during cross-border for live cattle (de Haan, 2016).

3.2.1. Rationale for the modeling of post-production losses

Environmental shocks are common among the poor livestock keepers in ASAL regions in Africa. The most common of them is drought. For example, one third of cattle, sheep and goats died during the two major droughts, which occurred in 1970s and in 1980s in the Sahel region. (Lesnoff, Corniaux, and Hiernaux, 2012; Ickowicz et al, 2012; Toure et al, 2012). Recently, about 12 million people suffered food insecurity as a result of the relatively mild drought that occurred between 2010 and 2012 (Oxfam, 2012).

Livestock losses are usually increased by environmental vagaries, which impacts adversely producers dependent on the sector. (Kabuko-Mariara, 2009; Thornton et al., 2009; Ifejika-Speranza, 2010). As a result, diversification especially to crop production is common among livestock keepers as a mitigation strategy (Herero et al, 2009). In the efforts to estimate the economic value of livestock in Ethiopia, a maximization/ optimization of utility function was made and estimated usning what was produced, consumed and how resources were allocated among households members under the constraint function (balancing outputs and inputs in dairy production) (Halloway, 2012; Adesugba, 2014).

From our perspective, we adopt this optimization approach uniquely. What specifically lies behind our position is to focus on live-ruminant post-production losses and tentatively determine a global loss function to minimize losses and ensure that livestock-keepers generate income that covers their overall expenditures. The basic idea behind our approach is that the objective function of producers in extensive and pastoral systems remains a composite utility function that balances their short-term consumption needs and long term herd building strategy to meet future consumption. That is why, they use markets in an opportunistic way. In this context, focusing on their market behaviors constitutes a key element to estimate the magnitudes of post-production losses.

The proposed study focuses on the Sahel and specifically Senegal due to diversity of its livestock post-production dynamics, which are typical throughout the Sahel. Senegal provides unique possibility to isolate the live-animal value chains, as it is a non-exporter of live-animals. With these considerations, we can safely assume that post-production losses exclusively depend on internal determinants and occur in a homogeneous context (in terms of currency, legal system, political actions, and cultural habits).

The livestock system in Senegal is dominated by traditional activities, e.g., those which cannot be measured only in quantitative or monetary terms and have also significant non-market drivers which may be as or more important than market drivers. This activity occupies 30 per cent of the population for about 36 per cent of agricultural GDP (1994-2000). Almost 68 per cent of households (90 percent of the rural and 52 of the urban households) own livestock. There are three main livestock sub-systems according to a North-South gradient: ***(i)*** the pastoral system at the Northern Senegal (the Ferlo), which occupies 64,000 km², 31 per cent of the national territory with density between 2 and 10,6 TLU per km²; ***(ii)*** the agro-pastoral systems, which occupies the rest of the country with a variety of rain-fed crops (millet, groundnuts, cotton etc.) and irrigated crops (rice, tomato and onion) in the groundnut basin, the Senegal River valley and the Southern Senegal with very high densities (26 TLU per km²); ***(iii)*** the intensive system is localized in urban and suburban areas, including the Niayes and Dakar.

We may, prior, respect a number of basic assumptions before designing a general framework.

3.2.2. Founding assumptions

i. A good understanding of the magnitude of post-production losses that pastoralist and agro-pastoralist households faced in the context of risks should help policymakers to design appropriate timely interventions to prevent effects on livelihoods. The recourse to markets fulfills specific requirements depending on species, production systems and timing of sale decisions. We can presume that as main animal producers, they are able to determine the best moment to sell animals in off-shock context.

ii. Despite the attention that the agricultural sector benefitted, very little reliable information on losses is available beyond the farm level (Sheahan and Barrett, 2016). Such information is not available at the pastoral household level. In addition, most of post-production losses in Sub-Saharan Africa occur on-farm. That is the reason for which we will insist more to model pastoral and agro-pastoral on-farm post-production losses before focusing on the value chain aspects because it would be difficult even impossible for us to follow the same animals sold by the pastoral households along the other nodes.

iii. We assume different sources of losses according to the periods of animal sales. We choose to investigate on a whole year. However, given the extreme climate variability that also affects price markets, we used the fractions of the time or pastoral sub-seasons usually considered by herders themselves. Thus, we distinguished five sub-seasons: $\boldsymbol{S_1}$ corresponding to the rainy season (locally called ***Ndungu*** in Fulani and going from mid-July to September), $\boldsymbol{S_2}$: transition period between rainy season and cold dry season (called ***kawle***, from October to November), $\boldsymbol{S_3}$:cold dry season (called ***dabbunde***, from December to February), $\boldsymbol{S_4}$: hot dry season (called ***ceddu***, from March to May) and $\boldsymbol{S_5}$: transition period between hot dry season and rainy season (called ***setselde***, from June to mid-July). Almost all questions were systematically repeated for each sub-period.

iv. We also considered herders as actors with usual bounded rationality except for some particular cases during which they maximize (minimize) their revenues from sales (total costs) and not their production.

v. Let us consider that in a favorable context without any shock occurring, if the producer decides to keep his animal until reaching what he considers the ideal moment to sell it, he bears an average management cost of $\overline{C}(\bar{A}-i)$ with i the index of the age of animal species: $i = 1, 2, \dots, 13, \dots$ and $\bar{A}$: average ideal selling age. Also, after reaching the ideal moment for selling this animal, the producer continues to bear an average management cost of$\bar{C}(i-\bar{A})$.

vi. We admitted as Barrett (2015) and (Goldsmith et al. (2015), the necessity to understand the microeconomic rational of actors before seeking PHL or PPL mitigation strategies. Thus, we focus a lot on motivations of sales of herders.

vii. We also admitted that a positive level of PPL should be economically viable if the main driver of the actor behavior is the maximization of the profit (minimization of the cost) - not the production optimization. Market-based game could push private actors to tolerate a positive level of loss if they expected best prices or too expansive mitigation strategies or technologies. Thus, it is important to explore for whom, a certain level of PPL could appear optimal. It depends on the actor-market interactions.

3.2.3. Main notations

The main notations are as follows:

- i the index of the age of animal species: $i = 1, 2, \ldots., 13, \ldots$
- x the number of heads sold
- AS: Animal species with MC: male cattle; FC: female cattle; MS: male sheep; FS: female sheep; MG: male goat; FG: female goat. So $as \in AS = \{MC, FC, MS, FS, MG, FG\}$
- $\bar{P}$: average selling ideal price
- $\bar{C}$: average management cost of the species
- $\bar{A}$: average ideal selling age
- A: maximum selling age
- S: pastoral sub-seasons with $S = \{S_1, S_2, S_3, S_4, S_5\}$ with $\boldsymbol{S_1}$ corresponding to the rainy season (locally called Ndungu from mid-July to September), $\boldsymbol{S_2}$: transition period between rainy season and cold dry season (called KAWLE, from October to November), $\boldsymbol{S_3}$:cold dry season (called DABBUNDE, from December to February), $\boldsymbol{S_4}$: hot dry season (called CEDDU, from March to May) and $\boldsymbol{S_5}$: transition period between hot dry season and rainy season (called SETSELDE, from June to mid-July)
- M_{PM}^{as}: number of dead animals by species during the pre-marketing phase
- V_{PM}^{as}: number of animal thefts by species during the pre-marketing phase
- Δ_{PM}^{as}: losses due to others physical factors than mortality and theft problems during the pre-marketing phase
- M_{MP}^{as}: number of dead animals by species during the marketing phase
- V_{MP}^{as}: number of animal thefts by species during the marketing phase
- Δ_{MP}^{as}: losses due to others physical factors during the marketing phase

3.2.4. On-farm post-production losses' modelling

<u>Losses during pre-marketing phase (PM)</u>

This concerns losses linked to mortality and thefts problems and also other physical factors. The dead and/or stolen animals are intended to be sold at the best prices. Let us voluntarily leave the physiological aspects outside our analysis and only address risk situations (Wane and Mballo, 2016).

The loss function per species during pre-marketing phase is as follows:

$$\boldsymbol{Loss_{PM}(as, x_i^{as}, P_i^{as}) = (\bar{P}^{as} * M_{PM}^{as}) + (\bar{P}^{as} * V_{PM}^{as}) + (\bar{P}^{as} * \Delta_{PM}^{as})}$$

<u>Losses due to actual sales (AS) whatever mortality and theft problems</u>

Let us consider $P_i^{as}(s)$ and $x_i^{as}(s)$ the average selling price and the number of sales for a given species at i-year old during a sub-season s. The loss function per species could take the following form:

$$\boldsymbol{Loss_{AS}\left(as, s, x_i^{as}(s), P_i^{as}(s)\right) = \sum_{i<\bar{A}}(\bar{P}^{as}\, x_i^{as}(s) - \bar{C}^{as} x_i^{as}(s)(\bar{A} - i)) + \sum_{i>\bar{A}}(\bar{P}^{as}\, x_i^{as}(s) + \bar{C}^{as} x_i^{as}(s)(i - \bar{A})) - \sum_{i=1}^{A} P_i^{as}\,(s) x_i^{as}(\mathrm{s})}$$

<u>Losses during the marketing phase (MP)</u>

This involves losses during to actual sales added to mortality and theft losses as above. We assume that animal dead and stolen could have been sold at the average price $\bar{P}$.

For the period 2015-2016, the loss function per specie could be written as follows:

$$\boldsymbol{Loss_{MP}(as, x_i^{as}, P_i^{as}) = (\bar{P}^{as} * M_{MP}^{as}) + (\bar{P}^{as} * V_{MP}^{as}) + (\bar{P}^{as} * \Delta_{MP}^{as})}$$

<u>Global losses per specie</u>

Global losses are calculated from reported losses during pre-marketing, actual sales and marketing phases.

$$\boldsymbol{Losses(as, x_i^{as}, P_i^{as}) = Loss_{PM}(as, x_i^{as}, P_i^{as}) + Loss_{AS}\left(as, s, x_i^{as}(s), P_i^{as}(s)\right) + Loss_{MP}(as, x_i^{as}, P_i^{as})}$$

Global loss function and optimization program

The global loss function summarizes global losses reported in monetary value for all species. It is the sum of all losses for each specie. Thus, it could be described as follows:

$$\begin{aligned}\boldsymbol{f(x_i^{as}(s), P_i^{as})} &= \boldsymbol{\sum_{as\in AS} Losses(as, x_i^{as}, P_i^{as}) = \sum_{as\in AS}\left(\,(\bar{P}^{as} * M_{PM}^{as}) + (\bar{P}^{as} * V_{PM}^{as}) + (\bar{P}^{as} * \Delta_{PM}^{as})\right)} \\ &\quad \boldsymbol{+ \sum_{i<\bar{A}}(\bar{P}^{as}\, x_i^{as}(s) - \bar{C}^{as} x_i^{as}(s)(\bar{A} - i)) + \sum_{i>\bar{A}}(\bar{P}^{as}\, x_i^{as}(s) + \bar{C}^{as} x_i^{as}(s)(i - \bar{A}))} \\ &\quad \boldsymbol{- \sum_{i=1}^{A} P_i^{as}\,(s) x_i^{as}(s) + ((\bar{P}^{as} * M_{MP}^{as}) + (\bar{P}^{as} * V_{MP}^{as}) + (\bar{P}^{as} * \Delta_{MP}^{as}))}\end{aligned}$$

The global loss function depends on two parameters: numbers and prices of animal sold for each specie at different ages and sub-seasons. The optimization program should be done on these parameters so as the producer minimize losses while meeting vital needs in terms of consumption, health, education and animal feedstuffs. Otherwise, we consider that the producer tries to minimize losses under the constraints that should generate income that covers expenses.

In the Senegalese Sahel, the global pastoral and agro-pastoral income is constituted at almost 94% by animal sales (Wane et al., 2015), the constraint on the income could be written as follows:

$$\sum_{as \in AS}(\sum_{s \in S}(\sum_{i=1}^{A} \boldsymbol{P_i^{as}(s) x_i^{as}(s)})) \geq \boldsymbol{Global\ expenses}$$

Finally, the optimization program could be:

$$\begin{cases} \boldsymbol{min\ f\left(x_i^{as}(s), P_i^{as}(s)\right)} \\ \boldsymbol{uc} \sum_{as \in AS}(\sum_{s \in S}(\sum_{i=1}^{A} \boldsymbol{P_i^{as}(s) x_i^{as}(s)})) \geq \boldsymbol{Global\ expenses} \end{cases}$$

3.3. Post-production losses in live-ruminants at producer level

Although post-production losses seem to occur more on-farm in Sub-Saharan Africa (Tomlins et al, 2007; Bechoff et al, 2011; FAO, 2011; Hodges et al, 2011; World Bank et al, 2011; Rosegrant et al, 2015; Sheahan and Barrett, 2016), it is highly probable that the distribution of losses varies due to the elongation of supply chains (urbanization, growing demand of meat and milk, rising income).

Depending to the four main objectives of post-production loss alleviating (food security, food safety, reducing waste, rising profitability), the magnitude of losses could be determinate through conventional methods of measurement. For the study case of Senegal, we proceeded to the monitoring of animals from the most important livestock market of Dahra to the terminal market consumption of Dakar (this would be detailed in the final empirical Report on the study-case of Senegal.

4. NEXT PHASES AND DELIVERABLES

The next phases of this work are as following:

- ***Final report on the empirical study-case of Senegal on by end of December 2016***
  To solve empirically the optimization programme by using data collected in the Senegalese Sahel on 202 pastoral and agro-pastoral according a climate transect North (more arid) – South (more watered).
    - Fieldworks were conducted in Senegal in November 2015 then in August and September 2016 (***1)*** to validate focus-group discussion findings at individual level; (***2)*** to identify/analyze marketing decisions within pastoral and agro-pastoral settlements in the Senegalese Sahel; (***3)*** to provide a synthetic view of these dynamics during the past 10 years (identification of main shocks and change); (***4)*** to investigate also the other VC actors (primary market collectors, conveyors, other market actors).
    - Thus, almost 200 pastoral settlements (grouping one or many households) were investigated.

5- WAYS FORWARD IN TERMS OF POST-PRODUCTION LOSSES IN LIVE-RUMINANT SECTOR

Before channeling more funds and mitigating loss related shocks and alleviating the effects on the livelihood of livestock stakeholders, there are still today many unanswered questions to solve.

i. To deepen the understanding of the value of losses in livestock and also in terms of welfare for people living under various sources of stress. Continue to work on evidence-based assessment methods is crucial.

ii. To launch a simulation exercise on the optimization programme given the large number of unknown variables. This should be complemented by more data collection on the livestock areas.

iii. To explore regional live animal value chain beyond the national one addressed in Senegal. For example, live-animals value chains in Burkina Faso spread wider as this country export to the coastal countries (Ghana, Côte d'Ivoire, Benin and Nigeria). The determinants of post-production losses would be both internal and external and thus, occur in a heterogeneous context in particular when animals are exported to English speaking countries (differences in language, currencies, cultures, legal systems and safety regulations, demand size, nature of risks…).

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